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Montana Dam Safety Outlet

No. 2 *Dam Safety Program, Department of Natural Resources and Conservation* October 1996

Serious Problems Develop at East Fork Dam
A Chronology of Events

On June 30, 1996, a forest service employee noticed muddy water flowing from the main embankment drain beneath East Fork Dam, a large earthen dam located on the East Fork of Rock Creek in Granite County. East Fork dam is owned by the State of Montana, managed by the Department of Natural Resources and Conservation (DNRC), and used for both irrigation and recreation. Any time sediment is seen in dam seepage, there is reason for alarm. Because the problem was immediately determined to be potentially serious, emergency action began. Outflow from the reservoir was maximized in an attempt to relieve pressures on the dam. On July 3, 1996, a large sinkhole appeared on the downstream face of the dam. Sinkholes are a result of earth material being removed slowly over time, leaving voids that eventually collapse. This sinkhole was located directly above the drain that was seeping muddy water, raising the suspicion that the problem might lie within the drain. Further investigation of the drain revealed that it contained an obstruction, located 38 feet back into the embankment . . . in the approximate location of the sinkhole. It was speculated by DNRC engineers that the drain might have become clogged, causing the embankment to drain improperly. It was then determined that (1) there was a significant threat of dam failure, and (2) an evacuation of downstream residents was warranted. Evacuation began on July 5, 1996. The evacuation order remained in effect until July 20, 1996, when it was determined that the reservoir had been lowered to a safe level. As the reservoir level was lowered, the amount of sediment in the seepage water decreased, a very positive sign. The Granite County Sheriff and local Disaster and Emergency Service Coordinator should be commended for their quick and efficient action in conducting the evacuation, in spite of only having a partially complete emergency action plan.

Because East Fork Reservoir supplies water essential to the 44 irrigators of the Flint Creek Water Users Association, it was imperative that immediate plans be made to rehabilitate the dam. Emergency funds and loans were located from several state agencies to assist in the cost of the rehabilitation, which is estimated to be somewhere around one million dollars. DNRC contracted with MSE/HKM, Inc., a well known consultant with extensive experience in dam design and construction, to investigate the problem and to design a repair. Their first action was to hire O'Keefe Drilling to drill several exploration holes in the dam embankment and foundation. At the same time, Mungus Construction was hired to excavate the drain and build necessary access roads. The results of the investigation revealed potential foundation problems and plugged perforations in the main drain. To further investigate the condition of the main drain and left abutment drain, Pace Construction was called in with their high-tech camera systems.

Several rehabilitation alternatives were considered as a result of the investigation including the installation

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of additional drains, the addition of a toe berm, the installation of relief wells, and the addition of a blanket drain to the upstream face of the right abutment. Rehabilitation construction is currently underway. If you have any questions regarding the events surrounding East Fork Dam, please contact Rick Bondy at 444-6656.

Technical Topic

THE SCIENCE OF SEEPAGE

Michael J. Oelrich, P.E. - Hydrometrics, Inc.

Although seepage problems have failed even new dams (Teton comes to mind), it is more commonly a problem in older dams where the seepage has had many years to develop its full potential steady-state condition. Seepage in older dams can lead to failure by either piping or embankment instability. In this article I'll take a look at several common warning flags that older dams have to warn of impending seepage problems and discuss how to apply the science of seepage to analyze these potential problems.

The hydraulic gradient of seepage flow through a dam is greatest at it's maximum steady-state phreatic position. This is important to this discussion of seepage, because it is the hydraulic gradient of the phreatic surface that produces the energy potential for internal erosion (piping) of the dam to occur. Although a new reservoir may have filled the first season, the full phreatic surface (water table) through the dam may not have been established that year. Dams, that are constructed with impervious zones and which have large fluctuations in reservoir levels during a normal year, may take years for the phreatic surface to fully develop. The potential for internal erosion in these dams may actually increase over time. The reason for the delay in establishment of the maximum steady-state phreatic surface is related to the relationship between soil permeability and soil saturation, but discussion of this relationship is outside the scope of this article.

Piezometers, placed in an embankment, are the primary means for monitoring the development of the phreatic surface in an embankment dam. Data from piezometers can be used to position the phreatic surface and determine its gradient through the embankment. As a general rule, a gradient at or exceeding unity, is a warning flag for potential problems with internal erosion of the dam. The maximum density of good, impervious dam construction material is approximately 125 pounds-per-cubic-foot (pcf) and its buoyant unit weight is about half that (125 pcf minus 62.4 pcf, the unit weight of water). The buoyant weight of the dam embankment, therefore, is approximately equal to the unit weight of water. As the gradient of the seepage flow approaches unity (1:1), the water has the necessary energy to displace the soil fill. By installing piezometers, the hydraulic gradient and, therefore, the potential for internal erosion can be determined.

Embankment drains are a special reason for concern because the hydraulic gradient into drains is almost always greater than unity. In order to prevent a drain from removing embankment material, a filter must be provided between the drain and the embankment material. A toe drain or foundation drain of unknown construction in an old embankment should be a warning flag, indicating a potential for internal erosion around the drains. In order for the drains to be protected from erosion of the surrounding embankment material, a soil filter should be provided that meets the following requirements:

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Science of Seepage (continued) . . .

$$D_{15}^{\text{filter}} / D_{85}^{\text{embankment}} < 5$$

D_{15}^{filter} is the gradation sieve size for which 15% of the filter soil is finer. $D_{85}^{\text{embankment}}$ is the gradation sieve size for which 85% of the embankment soil is finer. There are other filter design criteria as well. For instance, some specifications allow the above ratio to go as high as 10. A good source for filter criteria covering a broad range of conditions is the "CANMET (Canadian) Pit Slope Manual". By sampling and comparing the embankment and filter soils, the potential for internal erosion into the drains can be determined.

Many times seepage flow has been observed from the dam ever since the first filling, and the tendency might be to say "its not a problem - it has always seeped like that". I've heard this from the owners of many dams, but I'm convinced that seepage is like our children. We tend to forget just how small they once were until we get out the photo album. Measuring seepage flow creates a snapshot for the record that is vital for monitoring the effect that seepage may be having on a dam. The first obvious reason for monitoring seepage flow is to determine whether the seepage condition is stable or worsening. In order to answer this question, it is necessary to relate the amount of seepage to the reservoir level that is driving it. In order to identify any potential warning flags, therefore, data for both seepage flow and reservoir stage must be maintained over the life of the dam.

Characteristics of the seepage flow path can also be determined from seepage measurements. The equation used to predict seepage flow through soil includes a storage yield term, while the equation for flow through a pipe does not. Storage yield in soil will create scatter in the relationship between seepage flow and reservoir stage. If the measurement data is becoming less scattered over time, therefore, the seepage flow is being influenced more and more by internal erosion of its seepage path (piping). Measurement of the seepage will often give some indications if piping is developing within an embankment.

The final topic that I want to touch on concerns the impact of seepage on embankment stability. It is not uncommon for water to pond on the downstream toe of an embankment. Besides interfering with seepage measurement, this condition raises a warning flag for yet another reason. The slope stability of an embankment dam can be analyzed using a circular failure surface with an origin approximately above the slope toe and at an elevation near the top of the embankment and with a radius large enough for the circular arc through the embankment to intersect the top of the dam. The potential for this circular arc of soil to slide is determined by comparing the forces that contribute to a slide to the forces that resista a slide. One of the larger resisting forces is the weight of the soil at the toe of the slope. Buoyancy of this soil due to ponding water at the toe of the slope reduces this portion of the resisting force by half (see paragraph 3). Draining the water that is ponding on the toe of a dam will increase the stability of the embankment.

For all these reasons that I have discussed here, it is very important to monitor and analyze the effects of seepage on an older embankment dam. Dr. Parshall, the father of water measurement, was once quoted as saying "Unless one can express an opinion with numbers, he has not yet broached the boundaries of science". Approaching seepage monitoring as a science will go a long ways toward ensuring the safety of our older dam embankments.

"Every newsletter, we like to feature an article submitted by one of our readers on a technical Dam Safety topic. We welcome your submittals!"

Dam Fails in Meagher County

On May 29, 1996, an irrigation and stock water dam in Meagher County near White Sulphur Springs was overtopped and failed during high spring runoff. The dam had been overtopped earlier in the year, and a notch had been washed out of its center. Before the notch could be repaired, heavy runoff occurred again, and the dam failed. The resulting flood heavily damaged a county road approximately 1.5 miles downstream from the dam. The road was overtopped over a 300-foot-wide section. The downstream side of the road was washed away, and the downstream section of a drainage culvert was dislodged. No other damage was reported, other than debris in fences along the downstream channel. After an investigation, DNRC Dam Safety Program staff estimated that approximately 8 acre-feet was released from the dam with a peak flow of about 900 cubic feet per second (cfs). The dam measured approximately 19 feet high with a 1.2:1 (horizontal:vertical) upstream slope and a 2.25:1 downstream slope. The breach, which reached to the dam foundation, measured 57 feet wide at the top and 18 feet wide at the bottom. Nearly 1,150 cubic yards of embankment was removed during the failure. The emergency spillway was not large enough to handle the runoff flows.

Dam Repair Activities

The following are recently completed, ongoing, or planned construction activities on DNRC-regulated and other dams.

County	Dam	Owner	Type of Repair	Construction Start Date
Petroleum	Petrolia	DNRC	Spillway replacemcnt	June 1996
Silver Bow	Moulton	Butte-Silver Bow	Seepage lincr instln.	June 1996
Lewis & Clark	Willow Creek	Bureau of Reclamation	Sinkhole repair	July 1996
Lincoln	Glen Lake	Glen Lake Irr. Dist.	Spillway installation	July 1996
Big Horn	Tongue	DNRC	Road construction	August 1996
Jefferson	Delmoe	Pipestone Water Users	Add toe berm & drains	August 1996
Gallatin	Big Sky Co.	Big Sky Co. Water/Sewer	New dike construction	August 1996
Granite	E.F. Rock Cr.	DNRC	Sinkhole repair	August 1996
Missoula	Longpre	Gerhard Von der Ruhr	Outlet pipe repair	August 1996
Fallon	Lower Baker	Fallon County	Spillway replacement	September 1996
Mcagher	Jackson	Ron Jackson	Spillway enlargement	September 1996
Big Horn	Tongue	DNRC	Spillway replacement	1997

Volunteers Wanted

We need your input regarding two areas of the Dam Safety Administrative Rules in need of revision. The first area concerns spillway standards for new and existing dams. The other regards defining the traffic count per day that will likely result in the loss of life, for purposes of the Department's classification of the hazard potential of a dam. We are formulating a work committee that consists of engineers, dam owners, and folks that live within the evacuation area of a high hazard dam. Call Laurence Siroky (444-6816) if you would like to be on this committee. The results of the committee's work will be reported in this newsletter. If there are to be changes to the existing administrative rules, notice and hearings will follow.

SOME DOCUMENTED FAILURES OF DAMS IN MONTANA

Dam Name	County	Failure Type	Year Failed
Canyon Creek	Ravalli	Overtop-Partial Failure	1996
Unnamed	Meagher	Overtop	1996
Lackey	Missoula	Overtop	1995
Eureka Wastewater Pond	Lincoln	Piping	1995
McAlpine	Toole	Overtop	1995
Lisk Creek	McCone	Piping	1994
Brownes Lake	Beaverhead	Overtop	1984
Swift	Pondera	Overtop	1964
Lower Two Medicine	Glacier	Overtop	1964
Frenchman	Phillips	Piping	1952
Vaux #2	Richland	Overtop	1951
Vaux #1	Richland	Overtop	1951
Fred Burr	Ravalli	Piping	1948
Big Dry	Garfield	Piping/Spillway Failure	1939/1943
Porcupine	Valley	Overtop	1939
Pattengail	Beaverhead	Overtop	1927

Piezometer Installation Seminar a Success!

This year's Dam Safety Seminar, a "hands-on" course on the installation and evaluation of dam embankment piezometers, was held on May 7 and 8, 1996 in Lewistown, Montana. The course which was taught by David Jones, included both lecture and field demonstrations. David did an outstanding job, as reflected in the glowing evaluations! We had a very good turnout with a mix of dam owners, dam tenders, engineers, and drillers.

Everyone seemed to enjoy getting out in the field, where multiple techniques of installing piezometers were demonstrated on the Big Casino Creek Dam. The weather was warm and sunny, quite unusual for last spring! Several different types of piezometers were installed using holes drilled by different methods. The Natural Resource Conservation Service (NRCS) generously supplied a truck-mounted auger, and Montana Tech made available a hollow-stem auger rig. Roger Perkins, of Aquoneering, put on a special demonstration of several creative, cost effective techniques of installing piezometers, using a small, portable backhoe/auger rig he designed and built himself!

David Jones's lectures focused on the proper installation of piezometers to optimize data collection. He also emphasied data analysis and presented several applicable case studies, as well. Audience participation was encouraged, and some unique problems were brought up in the classroom.

We are looking for ideas for next years seminar or conference. Suggestions so far include: (1) seismic design of dams, (2) design and construction of drains and filters and (3) installation and use of weirs and flumes. Please contact the Dam Safety Section if you have any ideas or comments.

WILLOW CREEK DAM REPAIRS

Adapted from the Greenfields Irrigation District Newsletter, written by Scott Boelman, P.E.

A large sinkhole was discovered in the crest of Willow Creek Dam on the evening of June 28, 1996. Willow Creek Dam is located in Lewis and Clark County, near the town of Augusta. It is operated by Greenfields Irrigation District. The sinkhole was approximately 4 feet in diameter at the crest of the dam and widened to approximately 18 feet in diameter at the bottom of the sinkhole. The hole was approximately 29 feet deep. The formation of the sinkhole caused considerable distress to the dam embankment. The possibility of cavities, cracks and piping tunnels in the existing embankment makes further repairs necessary to ensure the integrity of the structure. Repairs are also required to the outlet works tunnel. Cracks in the outlet works tunnel lining indicate that the tunnel was damaged and may become further distressed.

What caused the sinkhole? In 1958 the outlet works tunnel of Willow Creek Dam collapsed due to negative pressures caused by an inadequately sized air vent at the upstream end of the tunnel. A large void was created within the dam around the outlet works following the tunnel collapse in 1958. This void, which was as large as a house, was not totally filled during repairs to the outlet works conduit in 1985. The movement of materials from the upper portion of the dam to the void surrounding the outlet works resulted in the development of the current sinkhole.

The following repairs are underway: (1) Excavating and replacing the embankment in the damaged portion of the dam, (2) Building a stability berm on the upstream dam face, (3) Placing a steel liner in approximately 95 feet of the outlet works tunnel, (4) Installing a new air vent, and (5) Replacing the gatehouse. The estimated cost of repairs to the dam is 1.6 million dollars. Greenfields Irrigation District is doing everything in its power to ensure that repairs are completed this fall and that the reservoir will be usable by next irrigation season.

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